The Socioeconomic Benefits of Earth Science and Applications Research: Reducing the Risks and Costs of Natural Disasters in the United States

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The federal investment in Earth science research from space, funded primarily through the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) has led to an improved understanding of the critical forcing functions behind changes in weather and climate. Earth science research has also resulted in a deeper understanding of the basic characteristics and observable phenomena of earthquakes and volcanic activity, as well as provided insights into the long term effects of worldwide changes in land cover and land use. Based on these results, scientists can reasonably expect that further investment in Earth science satellite data, modeling, and algorithm development will, among other things, vastly improve the ability to predict future weather and climate trends, and the onset of destructive earthquakes and volcanic activity. Such research will also contribute to the development of methods that enable more informed community and personal decisions regarding land use and other mitigative or preventative actions.

Changes in our environment can have profound effects on our lives. Severe storms and earthquakes often lead to sudden, extensive losses of property, business disruptions, and even loss of life. More gradual changes of weather and climate, such as drought and desertification, can be just as destructive over longer periods. The interannual cycles of El Niño and La Niña also lead to extremes of drought and precipitation (flooding) that stress communities and significantly affect their economic activities. Earthquakes and volcanic activity also exact major human and economic costs.

Changes in the patterns of where we live and the way we live also have a profound effect on the environment and on the magnitude of losses from natural climatological events. The dramatic increase in population density in coastal areas puts more lives and higher value property in the path of hurricanes. The growth of the industrial society has increased the introduction of potentially harmful chemicals into the atmosphere with possible effects on global temperature and storm patterns.

Within the United States and its territories alone, between 1980 and 2001, major weather and climate disasters created losses of more than $248 Billion (1998 dollars) and led to the loss of some 690 human lives.[1] In that same period, earthquakes and volcanoes cost the United States an additional $41 billion and 193 lives.

Natural disasters in other parts of the world have been even more destructive to human life and national economies. For example, in 1999, hurricane Mitch tore through Central America, leaving an estimated 11,000 people dead and destroying the infrastructure of whole villages and towns. Economic losses were staggering. Hurricane Mitch cost El Salvador close to $1 billion and Honduras more than $4 billion in direct property damage. Agricultural losses resulted in more than $1 billion additional costs for Honduras alone. Effects from the 1999 earthquake in central Turkey killed 15,466 people

[1] These data aggregate only weather and climate events that cost over one billion dollars per event. The sum of events that are less costly would add significant additional costs. Estimates of loss of life do not count a possible significant toll attributable in part to heat stress and other causes related to prolonged drought. Tom Ross and Neal Lott *A Climatology of Recent Extreme Weather and Climate Events*, National Climate Data Center Technical Report 2000-02., October, 2000 [http://www.ncdc.noaa.gov/ol/reports/billionz.html]

and led to losses of over $25 billion.[2] In many of these cases, the affected regions, especially in developing countries, are ill prepared to cope with the scale and severity of such natural calamities. Not only do they cause great human suffering and severely stress regional economies, they affect the rest of the world as well, both in the direct costs of human and economic assistance and in the interrupted supplies of goods and services in world trade. For example, the disaster assistance rendered by Canada, Europe, and the United States to all Central American countries affected by hurricane Mitch totaled between $720-$820 million.[3] These countries lost thousands of hectares of coffee and banana plantations.

One of the most severe long-term climatic phenomena on record was the El Niño/Southern Oscillation (ENSO) event of 1997-1998. In the span of one year, natural disasters attributed to ENSO affected more than 129 million people worldwide: an estimated 22,000 people lost their lives, approximately 378,216 were infected with water- and vector-borne diseases, and some 4.6 million people were displaced from their homes. The U.S. National Oceanic and Atmospheric Administration (NOAA) estimates worldwide economic damage at $36.6 billion.[4] In total, more than 22 million acres of forest and agricultural land were lost to fires, floods, and drought.[5]

A study conducted by Munich Reinsurance led to the startling revelation that the number of great natural catastrophes[6] worldwide increased fourfold from the 1950s to the 1990s. It also indicated that disasters currently carry a higher price tag than in the past, because the economic losses from natural catastrophes, after adjusting for inflation, increased by an astonishing factor of fourteen within the same timeframe.[7]

Much of the risk to life and property derives from uncertainties regarding the onset and severity of impending destructive events. Reducing the uncertainties surrounding the beginning and progress of severe weather conditions such as hurricanes, harsh winter storms, and flooding would allow local officials and individuals to prepare ahead, reducing economic losses and human suffering. Thus, better information can be translated into direct economic value. Greater accuracy in predicting future climate patterns, coupled with effective planning, would enable farmers, developers, and land managers to mitigate some of the harmful effects of possible changes, reducing future economic losses resulting from such changes. Lengthening the warning time for the onset of major earthquakes could sharply reduce losses of human life. In short, the practical applications of improved predictive capabilities will, if realized, result in considerable benefit to the U.S. and global economy and in fewer lives lost during natural disasters. NASA's Earth science research program is focused in large part on extending the nation's predictive ability far beyond current capabilities (Box A).

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[2] http://www.usaid.gov/hum_response/ofda/99annual/appendix.html

[3] http://hurricane.info.usaid.gov/

[4] http://www.usaid.gov/hum_response/ofda/98annual/intc.html

[5] Ibid.

[6] Munich reinsurance defines a natural as *great* "if the ability of the region to help itself is distinctly overtaxed, making interregional or international assistance necessary. This is usually the case when thousands of people are killed, hundreds of thousands are made homeless, or when a country suffers substantial economic losses, depending on the economic circumstances generally prevailing in that country."

[7] http://www.munichre.com/pdf/topics_2000_a5_e.pdf

BOX A.—NASA's Earth Science Program Focuses On Developing Advanced Predictive Capabilities For :

- Weather
  - Extending the useful range (~ weeks) of short-term predictions
- Climate
  - Improving accuracy of near-term (~ months) predictions
  - Developing long-term (~ years) predictions
- Natural Hazards
  - Experimental forecasting of hazard warnings.
  - Experimental forecasting of long- and mid-term predictions for certain events

Source: NASA

Estimating the scale of possible future social and economic benefits from Earth science research is subject to wide uncertainties. Nevertheless, considerable progress has been made in recent years in making such estimates, giving policymakers a much richer foundation upon which to make decisions regarding the potential payoffs from investments in Earth science research than they have had in the past. In particular, because Earth science research can lead to more precise predictions about future environmental changes, local, state, and federal agencies as well as private citizens can benefit from more precise planning and from avoiding certain costs. For example, improved information about the timing of floods help emergency planners to prepare to meet the challenge floods pose to property and human lives. More precise delineation of the extent of possible flood damage can also assist them in deciding who is most at risk and how best to mitigate that risk. It also helps people that confront only low risk hazards to avoid costly preparations they might otherwise be prompted to make in the face of greater uncertainty.

This document reports on the first phase of a research project that will explore the potential long-term socioeconomic benefits of investments in Earth science research. This first phase focuses on relatively short-term, well-documented domestic catastrophic events in the United States and its territories. Such a focus has enabled us to concentrate on cases for which the economic and human losses have been identified and quantified with greater certainty than in many other parts of the world. Since only one nation is analyzed, we have available relatively standardized measures. Among other things, this analysis examines the economic effects of gaining information that can assist in reducing risk and avoiding losses from catastrophic natural events. Future analysis will explore the socio-economic benefits of better information about long term climate change and changes resulting from large scale ecological practices, such as deforestation and agriculture. In addition, future analysis will expand the geographical coverage to examine the potential benefits of such research to the international community, as well as to the United States.

The Challenge of Natural Disasters

The costs of natural disasters can be very high. Over the past 21 years, the United

States has experienced 48 weather-related disasters in which overall damages/costs reached or exceeded $1 billion [Table 1]. The number of disasters exceeding $1 billion has increased over this period. Forty-one of 48 occurred between 1988 and 2000, leading to losses exceeding $180 billion. Seven of these took place in 1998–the most for any year on record. An estimated 199 deaths were linked directly to these seven disasters.

Earthquakes and volcanic eruptions, though they occur less frequently than weather and climate events, have also taken a toll in human lives and dollars. Table 2 summarizes the losses for major events between 1980 and 2000.

In the past three decades, investments in Earth science research and applications have led to markedly improved weather forecasts, both in accuracy and in length. Estimates of the severity, scope, and path of hurricanes, which cost the U.S. economy billions of dollars a year in damages and recovery, have also improved. These improved estimates have allowed local, state, and federal officials to prepare more effectively for their devastating fury.

Over the past three decades, NASA, NOAA, the U.S. Geological Survey (USGS), and other federal agencies have invested in Earth science research.[8] NOAA's research is primarily focused on oceans, weather, and climate [http://www.noaa.gov], in the expectation of improving the predictive capability of the National Weather Service. USGS conducts geological and land cover/land change research.

NASA has a comprehensive research program [http://www.earth.nasa.gov] that includes the collection of data from a wide variety of research satellites. Although NASA does not directly support much weather research, many of its climate research programs nonetheless provide the basic research and tools necessary for improving meteorological predictability. Further, it develops many of the instruments eventually used by NOAA for its environmental satellite programs.

In the paragraphs that follow, we examine several recent natural disasters, suggesting how improved prediction might have led to economic savings. In this first phase of our study, we focus on the value of acquiring better information and how it could assist the affected parties. The second phase will, among other things, estimate the economic benefits of obtaining such information.

In each of the following cases, this report also suggests how the data, information, and analytical tools could benefit planning, response, recovery, and mitigation. Although each natural disaster requires different information and analytical tools, there is also considerable overlap. For example, the information required to respond effectively to flooding would also apply to many hurricanes, as flooding is a major result of hurricanes.

Hurricane Floyd (September 1999).

This large, category 2 hurricane struck the Atlantic coast on September 16, 1999 making landfall in eastern North Carolina, where it dropped between 10 and 25 inches of rain in only two days. The resultant flooding caused far greater damage than wind or coastal storm surge. In North Carolina, seven thousand homes were destroyed, 17,000 rendered uninhabitable, and 56,000 were damaged. Some 1,500 people had to be rescued from flood waters. Pitt County, NC alone experienced damage costing an estimated $1.6

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[8] U.S. Global Change Research Program, *Our Changing Planet 2000*, Washington, DC: The Global Change Research Program, 2001.

billion. Some 51 people died in storm-related deaths in North Carolina. The Outer Banks, low-lying barrier islands, suffered serious beach erosion, and 500,000 people went without electrical power for periods lasting from days to weeks.

Additional, less damaging flooding occurred in South Carolina, Virginia, Maryland, Pennsylvania, New York, New Jersey, Delaware, Rhode Island, Connecticut, Massachusetts, New Hampshire, and Vermont. In all, Hurricane Floyd caused an estimated $6.0 billion damage and was directly implicated in 77 deaths.[9]

- *Applications of Earth Science Research to Effects of Hurricanes.* The data, information, and analytical tools developed in Earth science research are potentially applicable in all phases of a hurricane, from initial planning to recovery and future mitigation. The following paragraphs offer examples from among many of the sorts of assistance these outcomes of Earth science can provide:
    - <u>**Planning**</u> As a result of prior R&D, regions that are prone to hurricane impacts can use a variety of satellite and airborne data and geospatial tools to map the region and delineate areas particularly prone to impacts, including low-lying barrier islands and river drainages. In this effort, airborne lidar is particularly valuable for creating a detailed digital terrain map. Models developed using techniques developed by NASA and the Federal Emergency Management Agency (FEMA) of the potential extent of storm surges in fragile coastal areas can be especially important for emergency planners. Remote sensing analysis of the road networks would enhance the ability of emergency vehicles to reach people in the response phase. Such advanced planning may not only save lives, but also reduce the costs of emergency evacuation during the hurricane.
    - <u>**Response**</u> Satellite and airborne-derived maps are especially important for assessing the extent and severity of damage following a hurricane and planning the most effective response, including transportation lifelines.
    - <u>**Recovery and Mitigation**</u> During the recovery period and later, the experiences with the hurricane will indicate areas that are especially vulnerable to wind and rain damage. One of the most important efforts during this period is to attempt to improve planning to avoid future damage. Modeling using Earth science data and modeling tools can help local, state, and federal policymakers develop more effective building codes or indicate areas that should not be rebuilt.

Drought, Western Fires: Spring and Summer 2000.

The drought of 2000 began in the early spring when the accustomed spring rains did not materialize in many areas. By the end of August, after months of dry weather and unusually hot temperatures, some 35 percent of the country had experienced severe to extreme drought. The drought was most severe in West and Southwest, but it had a major impact on the Southeast as well. The drought caused about $4 billion in damage and associated costs and contributed to an estimated 140 deaths, nationwide.[10]

In the West, the drought, coupled with frequent high winds, led to the worst wildfire season in 50 years. Among the most destructive fire was the Los Alamos, New Mexico

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[9] http://www.ncdc.noaa.gov/ol/reports/billion/billionpaper.pdf.

[10] http://www.ncdc.noaa.gov/ol/climate/research/2000/sum/us_drought.html.

fire, which threatened the Los Alamos Federal Laboratory and destroyed 235 nearby homes and other structures.[11] Fires throughout the west caused an estimated $2 billion in damage and costs related to fighting fires. Fortunately, no lives were lost.

- *Applications of Earth Science to Effects of Drought and Fires* Here again, the products of Earth science research can help in preparing local communities prepare more effectively to cope with drought and the conditions that support wildfires. Satellite and airborne sensors developed for scientific research gather data on soil moisture, water reserves, vegetation biomass, and evaporation rates, enabling an area-wide survey of drought conditions as they develop. Predictive models developed using these and other data can be used to create forecasts of future precipitation rates and magnitudes. Extrapolation of these models to soil moisture and evaporation rates, allow emergency response teams to plan for potential future fires.

Flooding in the Northern Plains, April, May 1997.

During April and May of 1997, unusually warm temperatures led to an early heavy snowmelt, creating severe flooding along several rivers in North and South Dakota and Minnesota. Grand Forks, North Dakota was particularly hard hit by the flood, leading to evacuation of much of the downtown, lost crops, and damaged or destroyed homes and businesses. The overall economic toll in direct damage, lost business income, and cleanup costs reached about $3.7 billion. Eleven people lost their lives to the flooding.[12]

- *Applications of Earth Science to the Effects of Floods* With better information, the rate and extent of flooding can be predicted with considerable accuracy, allowing communities to prepare for the high water. The data products from Earth science research allow the creation of detailed topographic maps, land cover characterization, the extent and depth of snow cover, snow melt rates, and the amount and rate of precipitation. The analytical tools and modeling capabilities allow the development of hydrologic models, predicting the direction and speed of storms, and the dynamic modeling of floods as they develop.

Northridge, CA Earthquake: Jan. 17, 1994

The earthquake that struck Northridge in 1994 measured 6.7 on the Richter scale, causing extensive damage over an area of some 2,192 square miles in Los Angeles, Ventura, and Orange counties. Nearly 12,000 people required hospital treatment, and 72 lost their lives. Damages alone reached about $25 billion, with additional losses from reduced productivity and lost business. The Federal government alone spent $12.5 billion on response and recovery.[13]

- *Application of Earth Science to the Effects of Earthquakes* Although the science of earthquake prediction is in its infancy compared to the ability to predict the tracks and destructive damage of hurricanes, making preparation for a specific earthquake impossible at the present time, there is nevertheless much that can be done to prepare

[11] Although the Los Alamos wildfire began with an intentional, scheduled burn that raged out of control, the conditions that led to the extensive destruction are characteristic of natural wildfires.
[12] http://www.ncdc.noaa.gov/ol/reports/dakotaflood/dakotaflood.html
[13] http://www.fema.gov/NR/nr_0106.htm

for a cost-effective response to a possible future destructive earthquake.[14] Most regions prone to earthquakes are well known. Preparation derived from Earth science research includes the development of accurate topographic maps, including land cover types, urban features, and transportation lifelines. Modelling of alternate transportation routing assist in the recovery from the damaging effects of earthquakes. Further, techniques developed to further solid Earth science can be used to follow possible local surface deformations and fault movement, which may indicate areas of particular surface stress.

The Economic Value of Better Information

Providing better information about the onset and consequence of natural disasters can provide tangible economic benefits to governments, individuals, and businesses. These benefits come about in several different ways:

- *Reducing Uncertainty* More accurate, precise information can be used to reduce uncertainty about future events. For example, more accurate predictions about future weather and climate enable farmers and agribusinesses to estimate future crop yields, leading to reduced uncertainty about yields and prices. In economic terms, this can translate into fewer fluctuations in the futures market and help farmers, food producers, and food processors (among others) plan their business operations more efficiently. Similarly, the Caribbean Island of Guadeloupe is attempting to supply more of its power through utilizing its abundant wind, solar, and water resources. However, fluctuating wind and cloud cover reduces the contribution that wind and solar generation can make to the island's total needs. More detailed local forecasting would assist the island in managing those resources more effectively, thus boosting potential power generation.[15]
- *Information as a commodity* Information can be a commodity bought and sold on the market. Although the government produces free weather forecasts as a public good, private companies also make a profit developing and selling detailed, enhanced forecasts to a variety of industries. For example, to the energy generation industry, improving the predictive ability of forecasts by an average of only one degree can result in more efficient use of power generating resources and mean hundreds of thousands of dollars saved each year for electric utilities.[16] Many utilities employ their own forecasters at a high annual cost because of these potential large savings.
- *Information as knowledge* Information also provides a backbone of knowledge. Libraries, computer databases, textbooks, etc. all are storehouses of information and have value, even if the value is not as time-dependent for economic purposes as would be predictive data.

It is possible to develop many specific examples in each of these categories that apply to information derived from the data and analytic tools developed through Earth science research. However, information has no value unless it is made available to potential users and then put to use, whether for economic gain, education, entertainment,

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[14] Joanne M. Nigg, "Predicting Earthquakes: Science, Pseudoscience, and Public Policy Paradox," *Prediction, Science, Policy Making, and the Future of Nature*, Washington, DC: Island Press, 2000, pp. 135-156.

[15] Isabelle Bresson Le Figaro, July 7, 2001, p. 9.

[16] Del Jone, "Forecast: 1 Degree Is Worth $1B In Power Savings," *USA Today*, June 19, 2001, Money.

or to further scientific research. Hence, an important part of the task of making the results of Earth science research useful is to develop specific applications in each category.

After information is disseminated, it is quite easily transmitted and copied. For public good applications, such as responding to natural disasters, this capability is a marked benefit to society. However, the *market value* of information is immediately diminished after it is released unless the originator can acquire some method of retaining control, such as copyright or licensing.

In general therefore, information is not a single commodity whose worth can be easily evaluated. Each type of information is unique and often even the value is dependent on who receives the information and when as well as what actions are taken as a result of having the information on a timely basis.

An Illustration: Benefits of Improved Weather Prediction

Some of the ways in which improved information about natural hazards can produce economic savings can be illustrated by the case of weather forecasts. Adverse weather conditions, such as those caused by hurricanes and other severe storms, can impose substantial economic losses in the form of property damage, loss of life and limb, and interrupted business activities. Accurate information about potentially adverse weather conditions is economically valuable because it gives individuals and companies the chance to take actions to reduce these economic losses.

More accurate information about adverse weather provides economic benefits in two ways. First, better information makes it possible for people and businesses to undertake loss-reduction activities that should be undertaken, but which are not when there is imperfect information. Another, perhaps less well-recognized benefit of better information is that it can also reduce economic costs that arise when uncertainty about adverse weather causes government authorities, people, and business to "err on the side of caution" and undertake loss-reduction activities when they are not necessary.

For example, the kinds of cost savings that can be realized from better predictive ability are illustrated by the economic benefits of improved forecasts of hurricanes, which regularly strike coastal regions of the United States, imposing a variety of economic costs.

- *Direct Damage from Hurricanes* While current forecasting capabilities have done much to provide communities with advance warning of the onset of hurricanes, direct damage from major hurricanes has been substantial. Although much of this damage, such as destruction of structures, may not preventable, even if the landfall of hurricanes could be predicted with greater accuracy further in advance, it is widely believed that roughly *15-20%* of the damage from hurricanes can be prevented, when there is sufficient advance warning. Providing the capability to predict the path and intensity of hurricanes earlier in the course of the storm and with greater precision would lower the cost of taking preventive actions, thereby increasing the range of preventive actions that would likely to be undertaken.
- *Loss of Life and Limb* Hurricanes also exact a toll in lives lost. It is difficult to know how many additional lives, if any, would be saved by the increase in forecast accuracy indicated above. It is harder still, and somewhat controversial to attach an economic value to any lives that could be saved. Nonetheless, the potential for

reducing losses of life and limb should be counted qualitatively, if not quantitatively, as an economic benefit of improvements in the ability to forecast the severity and direction of hurricanes.

- *Reduced Damage Prevention Costs* Many of the costs of hurricanes and other natural disasters derive from the costs of preparation and damage prevention. In many cases, better information can also reduce these costs. For example, reducing the number of people that must be evacuated prior to a hurricane landfall would substantially reduce the costs to cities and counties, as well as residents (Box A).

Box A.–Reducing Evacuation Costs from a Hurricane

Each time a hurricane threaten to strike the east coast of southern Florida, emergency management officials in Broward County, which lies north of the city of Miami, have the difficult task of evacuating residents who may be in the hurricane's path. Because the highest natural elevation in the county is about 21 feet, the county is highly subject to storm surge, which can flood densely populated low-lying areas along the coast. The reach of storm surge is highly dependent both on distance from the shoreline and on elevation.

Emergency management officials reasoned that if they could create a more accurate topographic model than they had previously possessed, they might be able to reduce the number of people it was necessary to evacuate prior to a hurricane actually coming ashore in the county from the 300,000 previously estimated. Not only would a reduction in the number of evacuees reduce the stress on the population, it would save the county government and citizens significant costs. Certain facilities are particularly expensive to evacuate. For example, the county is home to a dozen hospitals, each one of which could cost up to $100,000 to evacuate in advance of a storm, not to mention the indefinable costs of mental and physical stress experienced by patients and their families.

Broward County officials contracted with Florida International University to develop a very accurate digital elevation model of the county based on elevation data acquired using an airborne laser sensor. The laser data were used to create a grid of elevation values every 2 meters, covering the urban area. The resulting model, when evaluated by a storm surge model, enabled Broward County to reduce the number of potential evacuees from about 300,000 to between only 130,000 and 150,000. This has resulted in a significant reduction of future costs to the county and its citizens.

In the future, Broward County will extend and improve the storm surge analysis by incorporating off shore bathymetry data it has recently acquired. The bathymetry data were also acquired by an airborne laser instrument, which is capable of measuring water depths of up to 150 meters. On the coast east of Broward County, this amounts to a distance from the coast of about 2 miles.

SOURCE: Broward County Office of Emergency Management

- *Reduced Overwarning* Based on current forecasting capabilities, the National Hurricane Center issues warnings to areas that are likely (though not certain) to be struck by hurricanes. Emergency preparedness officials have estimated that the costs of evacuating people from the path of a possible hurricane landfall is roughly $1 million per coastal mile.[17] Because of current uncertainties about the precise direction and onset of hurricanes, a typical landfall warning area is about 400 miles in length, even though the coastal area that is ultimately affected by an average hurricane once it hits land is only 100 miles. If predictions 24 hours in advance of the storm could be improved to the point that only 300 miles of coastline need to be evacuated, the costs of undertaking preventive actions that ultimately prove to be unnecessary are on the order of $100 million ($1 million/mile X 100 miles) for a typical hurricane. Alternative transportation routing, derived in part from models using remotely sensed data, could potentially lower evacuation costs still further.

Issues in Realizing the Economic Benefits of Better Information

Although better information about natural hazards has the potential to yield tangible economic benefits, the gain from better information depends not only on the quality of the information, but also on how it is used and disseminated. For example, improved information about the location of a floodplain, or earthquake fault line will have a greater potential to mitigate future losses if the information is made available in a way that encourages private individuals and businesses to act on the information. In some cases, regulatory actions by federal, state, or local authorities – for example in the form of building codes, or evacuation planning – may be needed to fully capture the cost savings from reduced uncertainty about natural hazards.

There are also certain limitations to the value of information derived from improved scientific information affecting predictions of future catastrophic events.[18] It is inevitable that natural disasters will occur each year around the world and that lives will be lost and property damaged, regardless of human intervention. It is clear that better scientific data has the potential to reduce the economic damage from natural disasters. What is not clear: What percent of the total losses can be reduced with better information? In other words,, if economic losses are increasing over time, can the predictive capabilities can be used to reduce the growth of this trend, even if the absolute economic values continue to increase?

Moreover, as noted above, better predictions of climatic changes are relatively useless without some additional action(s) being taken by individuals and governmental agencies. The timing of these actions is crucial to the type of magnitude of the impact. Further, the type of information also has to be matched to the type of disaster being evaluated.[19]

Finally, the level of spending of governmental agencies to plan for mitigating losses from disasters may not be well correlated with the actual losses incurred from any

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[17] Roger A. Pielke, Jr., "Floyd, the Fire Drill," Weatherzine," No. 18, Oct., 1999 [http://www.esig.ucar.edu/socasp/zine/18/editorial.html].

[18] Improved information provides social, as well as economic, benefits. The impact on the economy is measurable through the price system and through the estimated value of property and lives lost or saved. However, since the social benefits tend to be much more difficult to quantify, this report focuses on those impacts that can be translated into monetary terms and will discuss social benefits in qualitative terms.

[19] This is one area that will be addressed in the second phase of the study. We intend to examine the interaction of existing disaster planning with the products of additional research, providing more accurate, precise information.

given disaster. These limitations all feed into the difficulty surrounding the development of accurate estimates of the value of specific data and information sets.

Summary and Conclusions

Past improvements in earth observation capability have yielded better information about the onset, location, and impact of natural disasters and hazards. Armed with this information, both government and private parties have been able take measures to reduce the costs of living in a sometimes unfriendly natural environment.

Nonetheless, despite the increased ability of scientists to predict the occurrence and scope of natural disasters, a variety of human activities continue to increase the costs of natural disasters when they do occur. U.S. population density and value of infrastructure, especially along the coasts, has increased over the past two decades. People continue to build homes, businesses along vulnerable coastal areas, and floodplains, sometimes with financial and other incentives from federal, state, and local governments. Further, communities and individuals continue to drain wetlands that would ameliorate flooding and build river levies that force water to move downstream, contributing to downstream flooding. Federal and state policies to suppress small wild fires in forests lead to increased risk of large wildfires.[20]

Although significant strides have been made in providing information about natural hazards, major uncertainties about natural hazards and climate remain; there seems to be clear scientific scope for narrowing these uncertainties further by improving NASA's earth observation capability. It is clear that further improving predictions of the onset and progress of natural disasters would lead to significant economic savings to a wide variety of individuals and institutions. However, there is a larger gap between the scientific knowledge about components of the Earth's systems and the ability of applied users to put this knowledge to work in reducing the costs of natural disasters. Hence, additional efforts need to be made to improve the transition from research to applied use of data and information about natural disasters.

Future Research on Benefits of Earth Science Research

The next step in this study will be to conduct more detailed case studies and analyses of different examples of natural disasters. First, the study will compare the way planners and emergency personnel actually use particular data to reduce preventable losses. The usefulness of the improved data will present an indication of the future benefits of better predictions. This approach will also provide one indicator of what types of information and predictions NASA's studies and missions and other scientific research can produce that will be most useful to emergency planning and response professionals. Given the short time frame of this study, it will not be possible to analyze many different types of disasters. However, in the future this may be desirable since each different type of disaster will require different data (or similar data used differently) and therefore the scientific research and approach to predictions will also greatly vary.

Another aspect of the planned analyses will extend cost savings estimates to other Earth sciences research, such as interannual and long term climate change. Specifically, we will examine the benefits to be derived from better prediction of the timing and

[20] Michael Grunwald, "Disasters All, But Not As Natural As You Think," *Washington Post*, May 6, 2001, p. B-1.

strength of El Niño and La Niña for different regions. We will also explore the benefits of Earth science research in long term climate change and in predicting the course of vector borne disease, and other environmentally-related health effects. The following section on climate outlines the potential for estimating such benefits as well as the limitation of such analysis.

The Benefits of Improved Information on Climate Change

Although even if its precise order of magnitude cannot be quantified, reducing uncertainty about the scope and the pace of possible future climate change will provide real benefits. Several studies have shown that the potential economic costs caused by significant global warming plus the costs of adapting existing economic activities to mitigate its effects would be substantial. These studies also show that the costs of future global warming can be reduced significantly if steps are taken soon enough in advance to modify economic activities that might give rise to such warming.

The possibility of climate change poses a challenge to policymakers because there are potential costs to action as well as inaction. On the one hand, steps can be undertaken to reduce emissions that are the potential cause of climate change. But, taking these steps will be costly. For example, several different analyses imply that the economic costs of simply stabilizing the level of CO_2 emissions at 1990 levels would be on the order of one-half of one percent of Gross Domestic Product, or roughly $3 billion, while the costs of reducing CO_2 emissions by 20 percent from current levels would be roughly twice as large. For this reason, there is understandable caution in embracing such measures.[21]

On the other hand, if steps are not undertaken to reduce worldwide emissions of CO_2 and other gases, and significant global warming does take place, measures may need to be taken quickly to stabilize and reduce these emissions. The short-term costs of the behavioral changes that would be required to achieve such adjustments would be higher than if such changes had been encouraged sooner and took place over a longer period of time.

In each case, better information about future climate would be of economic value to policymakers because it would reduce the present range of uncertainty about the scope and pace of possible climate change. Lowering the level of uncertainty would reduce the likelihood of taking steps to reduce global warming which later prove unnecessary because the risk of significant global warming fails to materialize. It would also reduce the likelihood of failing to act in the face of a real threat. In short, information about the process of climate change could help lower the economic costs associated with both unwarranted action and inaction in the face of possible, though uncertain global climate change.

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[21] Darius W. Gaskins, Jr. and John P. Weyant, May 1993: "Model Comparisons of the Costs of Reducing CO_2 Emissions," *American Economic Review*. William B. Nordhaus, May 993: "Optimal Greenhouse-Gas Reductions and Tax Policy in the "DICE" Model," *American Economic Review;* and John Reilly and Neil Hohmann, May 1993: "Climate Change and Agriculture: The Role of International Trade," *American Economic Review*.

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The Tables

The following tables present evidence of the high levels of damage from various types of disasters. Each year, economic losses are in the billions of dollars and hundreds of lives are lost in the United States alone. And, in recent years, the value of losses from disasters appears to be increasing rapidly for a number of reasons. In part, losses have increased because many governmental responses to economic incentives and human behavior run counter to the efforts to mitigate potential future losses from disasters. Some of these incentives include:

- Population growth and migration to coastal areas
  - Increases in the value of at-risk property from increased demand
- Federal flood insurance programs
- Poor management of river basins and flood plains
- Use of chemicals and fuels that produce pollution and possibly contribute to global warming.

These tables point up the large potential payoffs from developing better predictive capability. For illustration, in the United States *if* hurricane predictions can be improved sufficiently (*and* planners *and* citizens are better prepared to act appropriately) to result in a 10 percent reduction in the loss of life, then using U.S. data, we could expect in the average year that about 15 lives would be saved. If we could, at the same time, reduce damage and preparation costs by 10 percent, then approximately $300 million would be saved in one year from hurricanes alone. Over time, many multiples of these numbers would represent savings to the economy. The actual potential for cost reductions will depend on many factors, including the complex relationship between research, the development of relevant applications, and their use by citizens and by local, state, and federal officials. Future research will attempt to quantify potential savings for a few specific cases.

Table I.—A Summary and the Comparison of the Effects of Droughts, Floods & Hurricanes in the U.S.

Type of Natural Disaster	Economic Costs	Deaths	Notes
Droughts	In 1995 by the Federal Emergency Management Agency reported that **$6-8 billion** is lost due to droughts every year. The National Climatic Data Center estimated the cost of the 1988 drought to be around **$40 billion.**	Drought in the United States seldom results directly in the loss of life. Deaths associated with drought are usually related to a heat wave or, in developing countries, a disruption in food supply leading to malnutrition and, possibly, famine. The National Climatic Data Center estimates heat-related deaths **between 5,000 and 10,000** for 1980 and 1988	Each year, some part of the U.S. has severe or extreme drought. Droughts can last for months, years or decades. Sometimes droughts are predicted up to a year ahead of time, but often there is no warning.
Floods	The annual average for the costs and losses from floods in the U.S. was calculated to be **$2.41 billion.** All sources agree that 1993 was the worst recent flooding year in terms of costs. There are wide discrepancies on the actual costs and the estimate ranges from **$15-27.6 billion.**	Floods have caused an average of **94 deaths per year** in fiscal years 1986-95. The 1993 Mississippi Valley floods, which is one of the worst in recent history, claimed **48** lives. Puerto Rico also had a flash flood in 1985 that killed **180** people.	In the US, a stream typically overflows 2 out of 3 years. A flood may last from hours to weeks and the warning time varies from seconds to months.
Hurricane	On average hurricanes lead to annual losses of **$1.2-4.8 billion.** Hurricane Andrew (1992) is the most costly recent hurricane event to affect the United States and according to the NCDC reports, it cost about **$30.475 billion** (on the U.S. mainland) when adjusted to 1996 dollars.	Data presented by the Environmental & Societal Impact Group indicated an average of **162 hurricane-related deaths per year.** However, if the value of **6000+ deaths** from the Galveston Hurricane of 1900 is omitted, the yearly average falls to about **100 deaths per year.** The worst hurricane in recent history, Hurricane Hugo in 1989, caused **49-86** deaths.	Typically the US is hit by 1.6 hurricanes/year and a class 4 or 5 hurricane strikes every 5.75 years. Hurricanes may last from minutes to weeks and the warning time typically ranges from 3 days to months.

The information presented in Table I are crude estimates obtained from the National Drought Mitigation Center (Source: http://enso.unl.edu/ndmc/enigma/compare.htm). The format of the original table was changed to suit the needs of the project. It is difficult to draw a meaningful comparison between the socioeconomic costs of droughts, hurricanes and floods since they vary widely in terms of frequency, duration and impact area. The statistics were compiled by NDMC from a variety of sources and although there are some discrepancies in them, they are generally similar.

Table 2a.—U.S. Extreme Weather and Climate Events: Hurricane

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
September 1999	$6.0	77	Large, category 2 hurricane makes landfall in eastern North Carolina, causing 10-25 inch rains in 2 days, with severe flooding in NC and some flooding in SC, VA, MD, PA, NY, NJ, NY, DE, RI, CT, MA, NH and VT
September 1998	$ 5.9	16	Category 2 hurricane strikes Puerto Rico, FL Keys, and Gulf coasts of LA, MS, Al, and FL panhandle, 15-30 inch 2-day rain totals in parts of AL/FL
August 1998	$ 1.0	3	Category 3 hurricane strikes eastern NC and VA; extensive agricultural damage from winds and flooding, with 10-inch rains in 2 days in some location
September 1996	$ 5.0	37	Category 3 hurricane strikes NC and VA, over 10-inch 24-hr rains in some locations, extensive agricultural and other losses
October-November 1995	$ 1.5 (2.6)	63	Category 1 hurricane hit LA and southeast US, severe flooding
October 1995	$ 3.0 (3.3)	27	Category 3 hurricane strikes FL panhandle, AL, western GA, eastern TN and the western Carolinas, causing storm surge, wind and flooding damage
September 1995	$ 2.1 (2.3)	13	Category 2 hurricane devastates US Virgin Islands
September 1992	$ 1.8 (2.2)	7	Category 4 hurricane hits Hawaiian island of Kauai
August 1992	$ 27.0 (32.4)	61	Category 4 hurricane hits FL and LA, high winds damage or destroy over 125,000 homes
August 1991	$ 1.5 (2.0)	18	Category 2 hurricane, mainly in coastal NC, Long Island and New England
September 1989	> $9.0 (12.6) (about $7.1 (9.9) in the Carolinas)	86	Category 4 hurricane devastates SC and NC with ~20 foot storm surge and severe wind damage, after hitting Puerto Rico and the US Virgin Islands; deaths: 57 in the US mainland, 29 US Islands
August – September 1986	$ 1.3 (2.2)	4	Category 3 hurricane, Fl to LA
August 1983	$ 3.0 (5.4)	21	Category 3 hurricane, TX

Table 2b.—U.S. Extreme Weather and Climate Events: Flooding

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
October-November 1998	$ 1.0	31	Severe flooding in SE Texas from 2 heavy rain events: 10-20 inch rainfall totals
April-May 1997	$ 3.7	11	Severe flooding in ND, SD and MN due to heavy spring snow melt
December 1996-January 1997	$ 3.0	36	Torrential rains (10-14 inches in 2 weeks) and snow melt produce severe flooding over portions of CA, WA, OR, ID, NV and MT
February 1996	$ 1.0	9	Very heavy, persistent rains (10-30 inches) and melting snow over OR, WA, ID and western MT
January 1996	$ 3.0	187	"Blizzard of '96". Very heavy snowstorm (1-4 feet) over Appalachians, Mid-Atlantic and Northeast, followed by severe flooding in parts of same area due to rain and snow melt
May 1995	$ 5.0 – $ 6.0 (5.5 – 6.6)	32	Torrential rains, hail and tornadoes across Texas, OK and southeast LA, southern MS, with Dallas and New Orleans area (10-25 inch rains in 5 days) hardest hit
January – March 1995	> $ 3.0 (3.3)	27	Frequent winter storms cause 20-70 inch rainfall and periodic flooding across much of CA
October 1994	$ 1.0 (1.1)	19	Torrential rain (10-25 inches in 5 days) and thunderstorms cause flooding across much of southeast TX
Summer 1993	$ 21.0 (23.1)	48	Severe, widespread flooding in central US (Midwest) due to persistent heavy rains and thunderstorms
May 1990	$ 1.0 (1.3)	13	Torrential rains cause flooding along the Trinity, Red and Arkansas River in TX, OK, LA and AR

Table 2C.—U.S. Extreme Weather and Climate Events: Drought

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
June-September 1980	$ 20.0 (44.0)	10,000	Central and eastern US. Deaths include heat stress-related
Summer 1986	$ 1.0 - $ 1.5 (1.6-2.4)	100	Severe summer drought in parts of the southeastern US with severe losses to agriculture
Summer 1988	$ 40.0 (56.0)	5,000	1988 drought in central and eastern US with very severe losses to agriculture and related industries; deaths $5,000 – 10,000, include heat stress-related
Summer 1989	$ 1.0 (1.4)	0	Severe summer drought over much of the northern plains with significant losses to agriculture
Fall 1995 – Summer 1996			
Summer 1998	$ 5.0	0	Severe drought in agricultural regions of southern plains. TX and OK most severely affected
Summer 1999	$6.0 – 9.0	200	Severe drought and heat wave from TX/OK eastward to the Carolinas
Summer 2000	$>1.0 B	502	Very dry summer and high temp, eastern U.S. Extensive agricultural losses
	$4.0	140	Severe drought, persistent heat over south-central and southeastern states causing significant losses to agriculture and related industries

Table 2d.—U.S. Extreme Weather and Climate Events: Severe Weather/Tornadoes

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
May 1999	$ 1.1	55	Outbreak of F4-F5 tornadoes hit OK, KS, TX, TN, Oklahoma City area hardest hit
January 1999	$ 1.3	17	Two outbreaks of tornadoes in 6-day period strike TN, AK
May 1998	$1.5	1	Very damaging severe thunderstorms with large hail over wide areas of Minnesota
Winter-Spring 1998	$ >1.0	132	Tornadoes and flooding related to El Niño in southeastern states
July 1994	$ 1.0 (1.1)	32	Remnants of slow-moving Alberto bring torrential 10-25 inch rains in 3 days, widespread flooding and agricultural damage in parts of GA, AL and FL panhandle
March 1993	$ 3.0 – $ 6.0 (3.3 – 6.6)	270	"Storm of the Century" hits entire eastern seaboard with tornadoes (FL), high winds and heavy snows (2-4 feet)
December 1992	$ 1.0 - $ 2.0 (1.2-2.4)	19	"Nor'easter of '92". Slow-moving storm batters northeast US coast, New England hardest hit
October 1991	$ 2.5 (3.3)	25	Oakland, CA firestorm due to low humidity and high winds

Table 2e.—U.S. Extreme Weather and Climate Events: Snow/Ice

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
January 1998	$ >1.4	16	"Blizzard of '98". Intense ice storm hits ME, NH, VT, and NY, with extensive forestry losses
January 1996	$ 3.0	187	"Blizzard of '96". Very heavy snowstorm (1-4 feet) over Appalachians, Mid-Atlantic and Northeast, followed by severe flooding in parts of same area due to rain and snow melt
February 1994	$ 3.0 (3.3)	9	Intense ice storm with extensive damage in portions of TX, OK, AR, LA< MS, AL, TN, GA, SC, NC and VA
January 1985	$ 1.2 (2.0)	0	Severe freeze in central/ northern FL; damage to citrus industry
December 1983	$ 2.0 (3.6)	0	Severe freeze in central/ northern FL; damage to citrus industry

Table 2f.—U.S. Extreme Weather and Climate Events: Wild Fire

DATE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
Spring-Summer 2000	$4.0	0	Severe fires in western states because of drought and frequent winds, nearly 7 million acres burned
May 2000	$1.0	0	Originally a prescribed fire, it burned on for a month, 47,650 acres burned, 235 structures destroyed, 25,000 people evacuated, Los Alamos National Laboratory damaged
Summer – Fall 1994	$ 1.0 (1.1)	-	Severe fire season in western states due to dry weather
Fall 1993	$ 1.0 (1.1)	4	Dry weather, high winds and wildfires in Southern CA

Table 3.—Socioeconomic Effects of Major U.S. Earthquakes, 1980-2000

DATE	LOCATION	MAGNITUDE	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
February 28, 2001	Puget Sound, Washington	6.8	$2.0	1	110 houses destroyed, 126 with major damage; located in the same general area as a magnitude 7.1 earthquake on April 13, 1949
September 3, 2000	Yountville, California	5.2	$10 to $50 mil	0	The largest earthquake to hit the area since 1969
October 16, 1999	Hector Mine, California	7.1	0	0	The earthquake occurred in the Mojave Desert, 32 miles north of Joshua Tree, California; it was felt strongly in Las Vegas and caused the derailment of an Amtrak train

TABLE 3, Cont.

January 17, 1994	Northridge, California	6.9	$15	57	The 1994 event is the most damaging earthquake to strike the United States since the San Francisco Earthquake of 1906. In terms of financial loss, the earthquake is also one of the worst natural disasters in U.S. history, comparable to Hurricane Andrew in 1992. Over 40,000 structures damaged.
September 20 and 23, 1993	Klamath Falls, Oregon	5.9, 6.0	$7.6 mil	3	The largest to have occurred in Oregon in the 20th century.
March 25, 1993	Portland, Oregon	5.6	$30 mil.	0	The largest earthquake in the Pacific Northwest since the Elk Lake and Goat Rocks earthquakes of 1981; lack of injuries or deaths, probably because it occurred in the early morning
June 28, 1992	Landers, California	7.3 (7.6)	$ 100 mil.	1	The earthquake occurred in a sparsely populated area between Palm Springs and Barstow in southern California. Following it by three hours (and occurring while TV news coverage of the Landers earthquake was being broadcast live from Caltech), the Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately claimed no lives.
June 28, 1991	Sierra Madre, California	5.8	$40 mil.	2	
October 17, 1989	Loma Prieta, California	6.9	$10	62	$2 billion of that amount is for San Francisco alone and Santa Cruz officials estimated that damage to that county will top $1 billion.
October 1, 1987	Whittier Narrows, California	5.9	$358 mil.	8	Severe damage was confined mainly to communities east of Los Angeles and near the epicenter.
October 28, 1983	Borah Peak, Idaho	7.3	$12.5 mil	2	The largest earthquake to ever hit Idaho, both in terms of magnitude and the amount of property damage
			$27.5	**136**	

Table 4. Socioeconomic Effects of U.S. Volcanic Eruptions, 1980 – 2000

DATE	LOCATION	ESTIMATED ECONOMIC LOSSES (Billions $)	ESTIMATED RELATED DEATHS	NOTES
May 18, 1980	Mount St. Helens, Washington	$1.1 (amount does not include money for personal property losses, cost of ash clean-up, or loss of tourism)	57	Initial debris avalanche and lateral blast removed the upper 396 meters of the volcano, killed 57 people, and triggered debris flows that temporarily stopped shipping on the Columbia River and disrupted highways and rail lines. The blast devastated 596 square kilometers, and destroyed timber valued at several millions of dollars. Measureable amounts of ash fell as far east as North Dakota.
1983 - today	Kilauea, Hawaii	*	*	Nearly 78 square kilometers covered by lava and over 180 dwellings destroyed including, in 1990, the entire historic community of Kalapana. 121 square hectometers of new land added to the island of Hawaii
March 25, 1984	Mauna Loa, Hawaii	*	*	Hilo, the largest city on the Island of Hawaii, was threatened by lava flows. When the eruption stopped 3 weeks later, lava flows were only 6.5 kilometers from buildings in the city of Hilo.
1986	Augustine Volcano, Alaska			Ash plume disrupted air traffic and deposited ash in Anchorage. A dome built in the crater led to fear of dome collapse triggering a tsunami along the east shore of Cook Inlet, as happened in 1883, when a part of the volcano's summit collapsed into the sea. Within one hour, a tsunami as high as 9 meters crashed ashore on the coast of the Kenai Peninsula 80 kilometers away. No one was killed and property damage was only minor because the tsunami hit at low tide.
1989-1990	Redoubt Volcano, Alaska	$160 mil.		Debris flows caused temporary closing of the Drift River Oil Terminal. A 747 jet aircraft temporarily lost power in all 4 engines when it entered the volcanic ash plume, and it would have crashed had its engines not been started just 1,219 meters above the mountain peaks toward which it was heading. The damage and loss of revenue from ash and debris flows total about $160 million, making this eruption the second most costly in the history of the United States.

** As land development expands toward areas of relatively high hazard, the threat to life and property on Hawaii will increase accordingly.*